Post-Harvest Operations and Processing of Fruits, Vegetables, Spices and Plantation Crop Products
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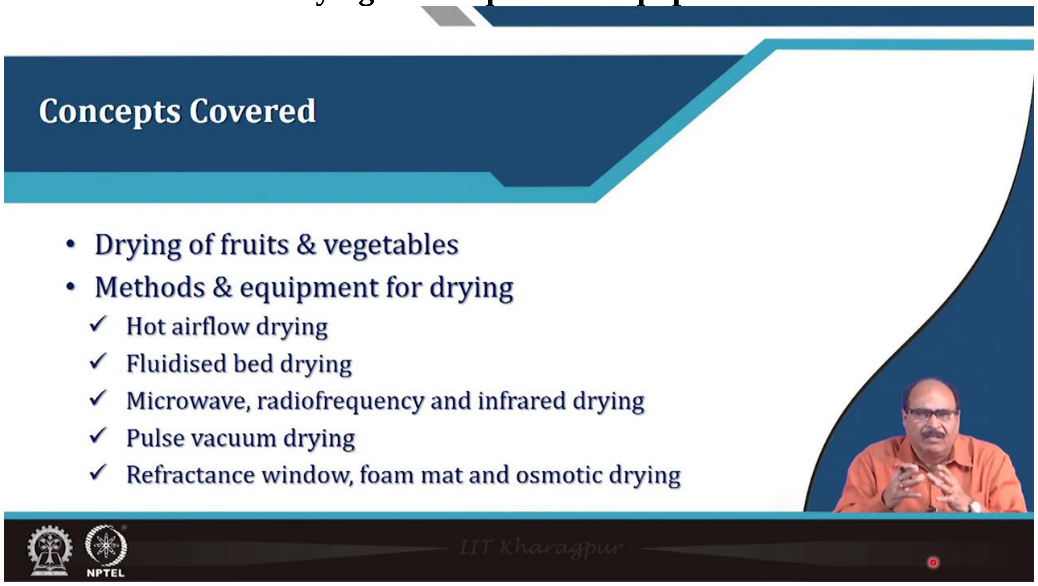
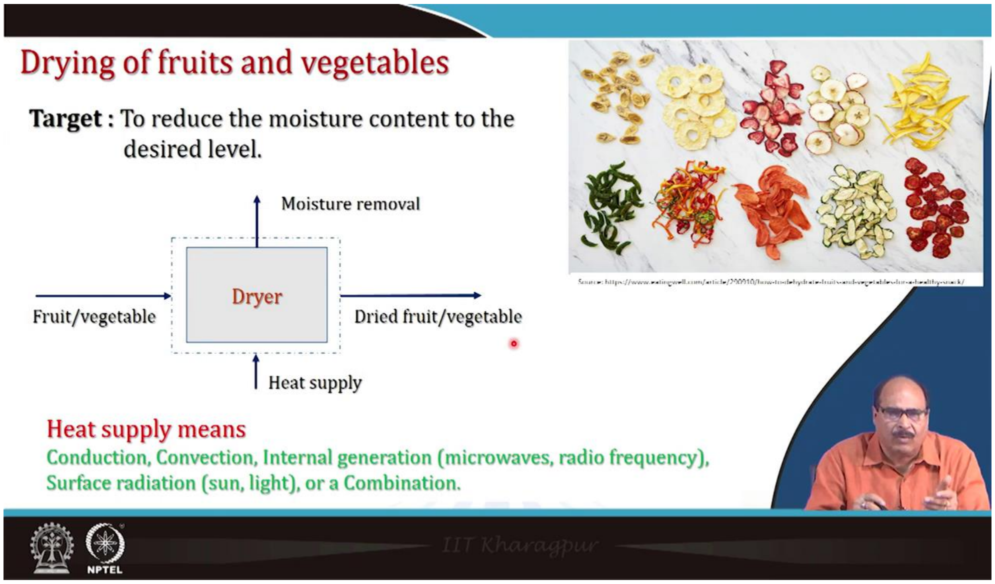
Lecture 31
Drying Techniques and Equipment

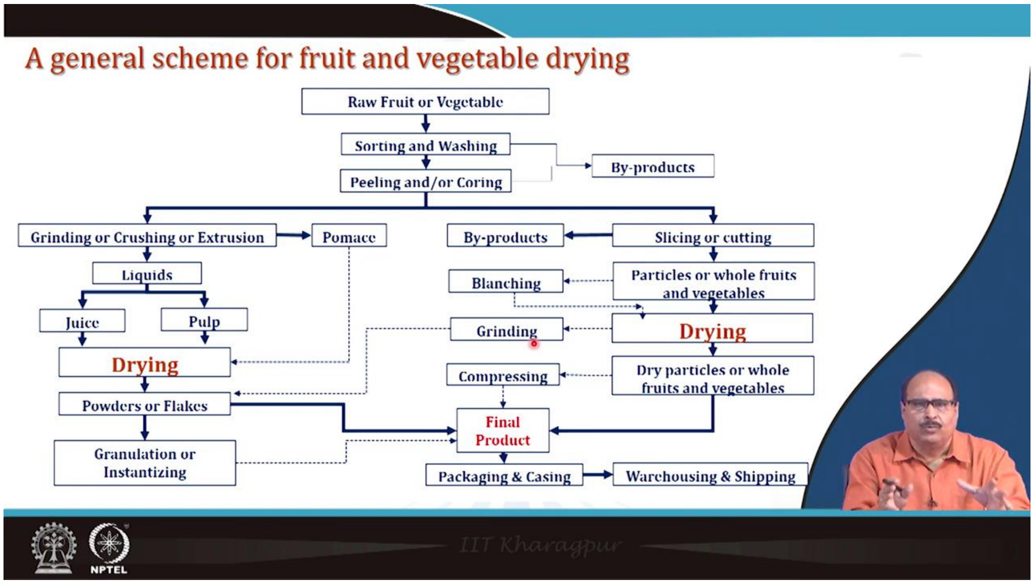


The concepts covered in this lecture include drying of fruits & vegetables, and the methods and technologies for drying of the fruits and vegetables which may be beneficial from the quality point of view. So, the methods and equipment used here will include hot airflow drying, fluidized bed drying, microwave, radiofrequency, infrared drying, pulse vacuum drying, and refractance window, foam mat, and osmotic drying.



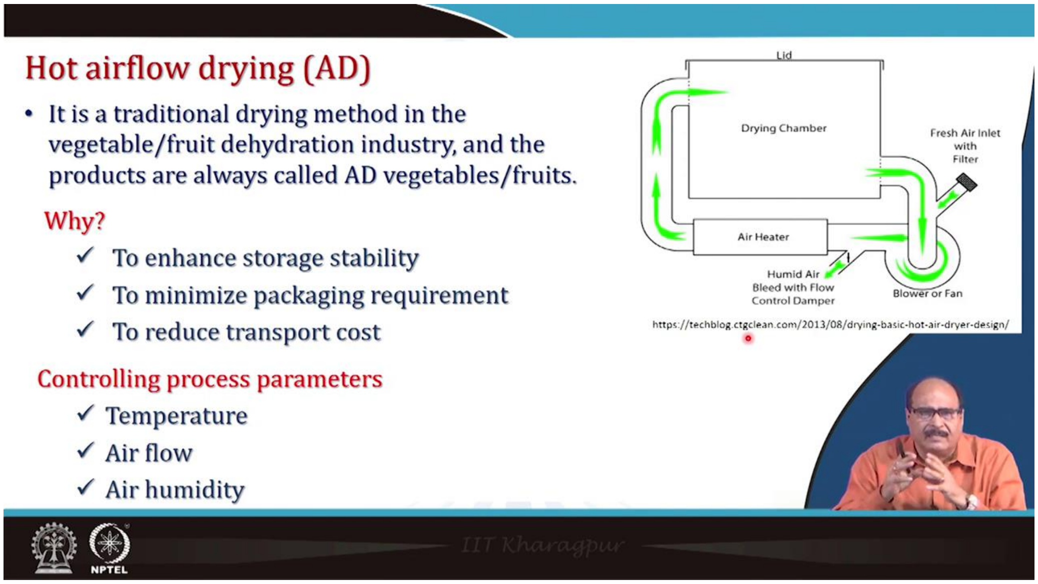
Drying of fruits and vegetables

The drying and dehydration mainly is to reduce the moisture content of the material to the desired level. As shown in figure, fruits and vegetables are put into the dryer, where heat is supplied. In general, the heat supply sources may be conduction, convection, internal generation of heat through microwaves and radio frequency or even the surface radiation like sunlight or a combination of various methods. The dried fruits and vegetables are the output of the dryer along with the removal of moisture.



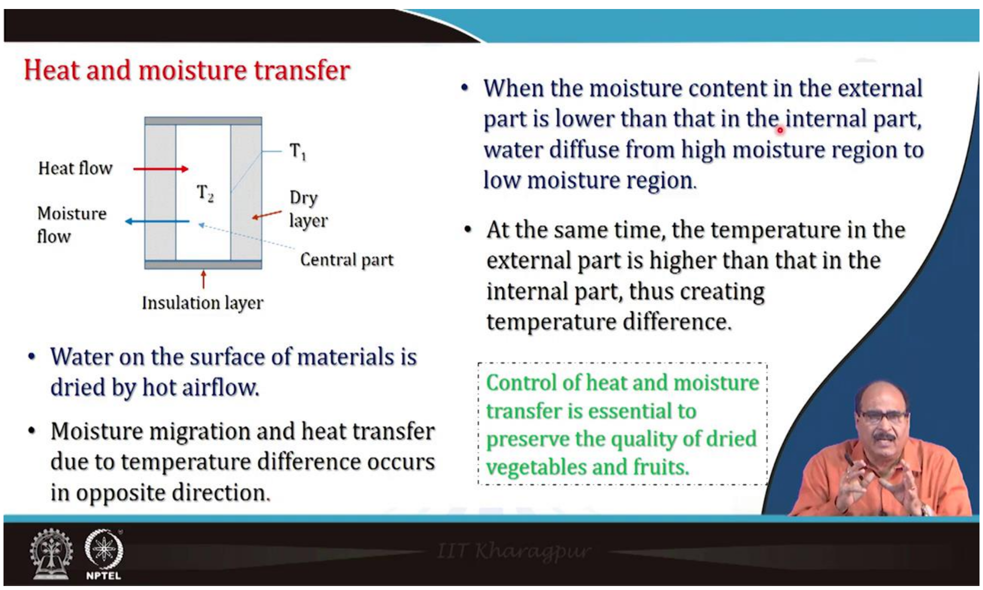
A general scheme for fruit and vegetable drying

The raw fruits and vegetables after subjecting various pretreatments like sorting, washing, peeling, coring etc. and then can be subjected to two major treatments depending upon their forms and nature of the dried product. Either the products are subjected to slicing or cutting, or grinding, crushing, or extrusion. After the pretreatments, the products are dried by a suitable drying technique. After the drying process, the products are either in the form of dry particles or whole dried products. After the crushing/grinding operation, the extracted juice and pulp are dried to produce dry powders or flakes. All these dehydrated products are properly packed prior to ware housing and shipping.



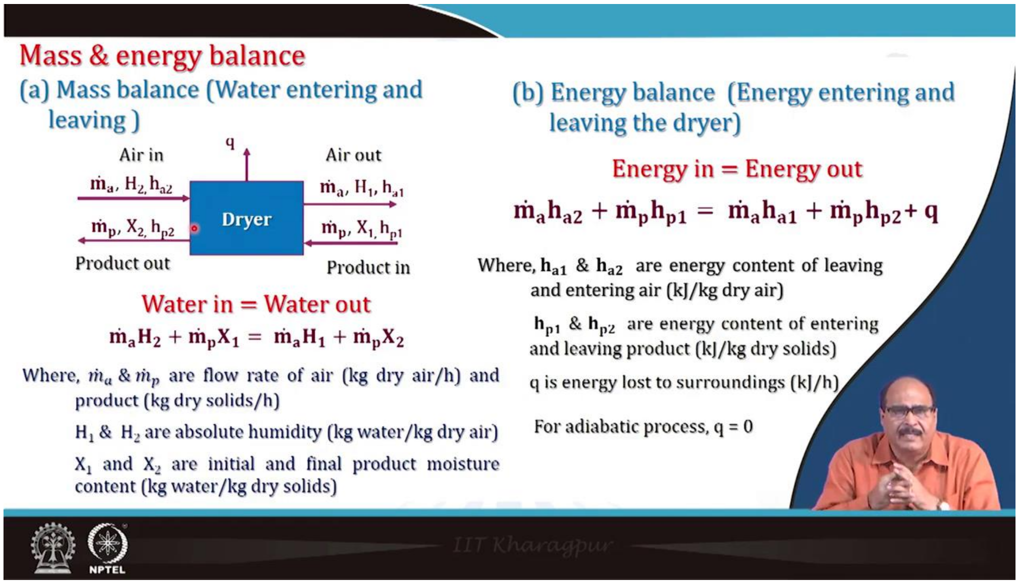
Hot air flow drying

It is a traditional drying method in the vegetable/fruit dehydration industry, and the products are always called AD vegetables/fruits. This drying is used to enhance the storage stability, to minimize packaging, requirement to reduce transportation cost. In this drying technique, temperature, air flow, and air humidity can be controlled.



Heat and moisture transfer

In the drying chamber, the heat is flowing inside and the moisture is removed from the dryer. T_1 is the temperature of the product that is put into the dryer, and the temperature is raised to T_2 with the help of heated air. In the drying chamber, some insulation is provided so that there is no heat loss. So, water on the surface of the material is dried by hot air flow. Moisture migration and heat transfer due to temperature difference occur in the opposite direction, as shown in the figure. Heat is flowing from outside to inside and moisture is going from inside to outside because the material kept inside. So, when the moisture content in the external part is lower than that in the internal part, water diffuse from high moisture region to low moisture region. At the same time, the temperature in the external part is higher than that in the internal part. Thus, it creates a temperature difference, which facilitate the moisture removal. Control of heat and moisture transfer is essential to preserve the quality of the dried vegetables and fruits.



Mass & energy balance

(a) Mass balance (Water entering and leaving)

$$\text{Water in} = \text{Water out}$$

$$\dot{m}_a H_2 + \dot{m}_p X_1 = \dot{m}_a H_1 + \dot{m}_p X_2$$

Where, $\dot{m}_a$ & $\dot{m}_p$ are flow rate of air (kg dry air/h) and product (kg dry solids/h)

H_1 & H_2 are absolute humidity (kg water/kg dry air)

X_1 and X_2 are initial and final product moisture content (kg water/kg dry solids)

(b) Energy balance (Energy entering and leaving the dryer)

$$\text{Energy in} = \text{Energy out}$$

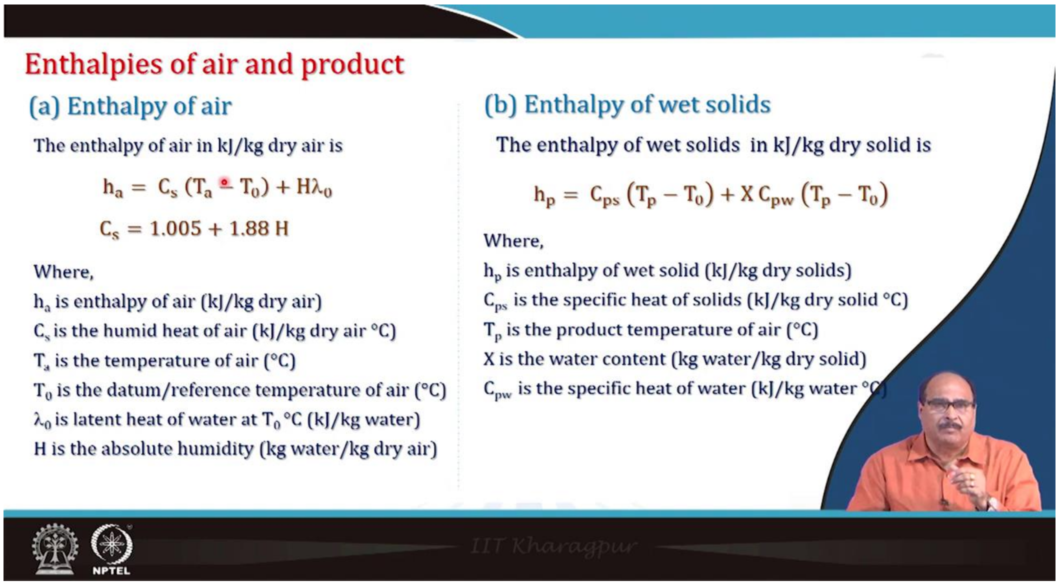
$$\dot{m}_a h_{a2} + \dot{m}_p h_{p1} = \dot{m}_a h_{a1} + \dot{m}_p h_{p2} + q$$

Where, h_{a1} & h_{a2} are energy content of entering and leaving air (kJ/kg dry air)

h_{p1} & h_{p2} are energy content of entering and leaving product (kJ/kg dry solids)

q is energy lost to surroundings (kJ/h)

For adiabatic process, q = 0



Enthalpies of air and product

(a) Enthalpy of air

The enthalpy of air in kJ/kg dry air is

$$h_a = C_s (T_a - T_0) + H\lambda_0$$

$$C_s = 1.005 + 1.88 \text{ H}$$

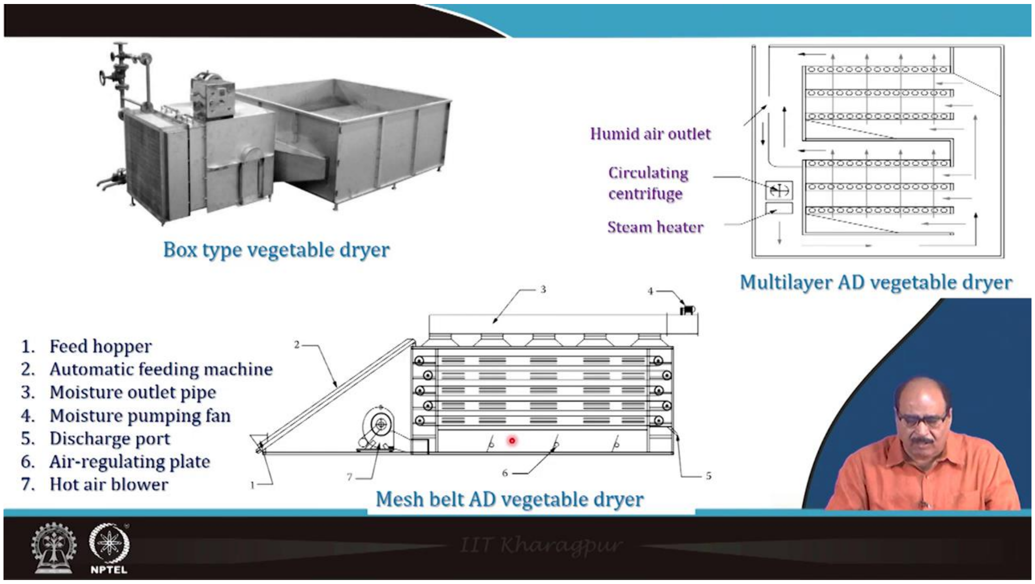
Where, h_a is enthalpy of air (kJ/kg dry air), C_s is the humid heat of air (kJ/kg dry air °C), T_a is the temperature of air (°C), T_0 is the datum/reference temperature of air (°C), λ_0 is latent heat of water at T_0 °C (kJ/kg water), H is the absolute humidity (kg water/kg dry air).

(b) Enthalpy of wet solids

The enthalpy of wet solids in kJ/kg dry solid is

$$h_p = C_{ps} \left(T_p - T_0\right) + X\, C_{pw} \left(T_p - T_0\right)$$

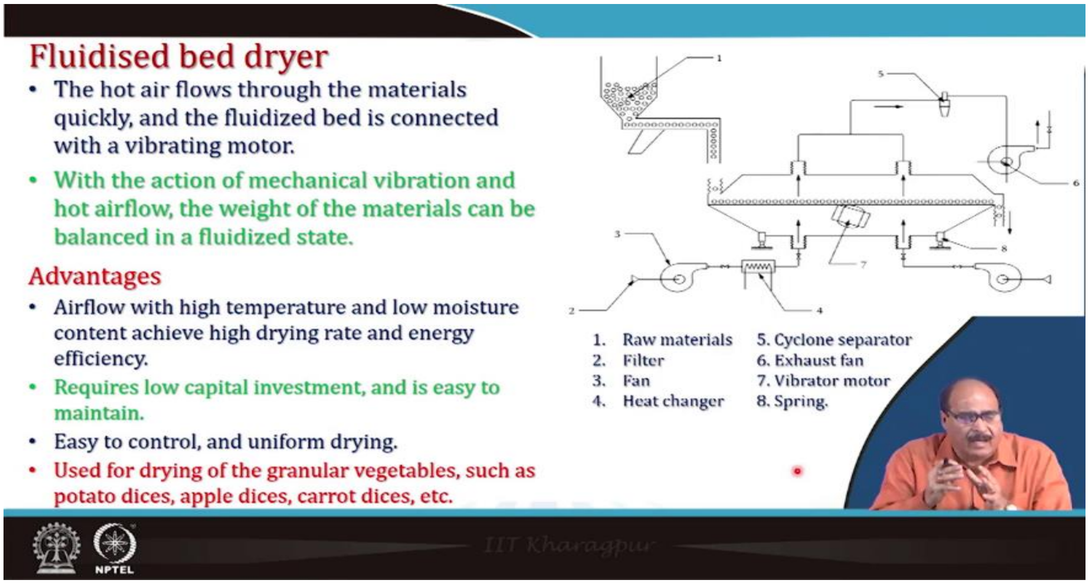
Where, h_p is enthalpy of wet solid (kJ/kg dry solids), C_{ps} is the specific heat of solids (kJ/kg dry solid °C), T_p is the product temperature of air (°C), X is the water content (kg water/kg dry solid), C_{pw} is the specific heat of water (kJ/kg water °C).



The figure represents the schematic diagram of box type vegetable dryer. Another figure shows the multilayer AD vegetable dryer. The product is loaded into the drying chamber in different layers one above the other. There is a sufficient gap between the layers so that the hot air, steam is passing. Through this outlet channel, humid air goes out or in some cases, it is recirculated.

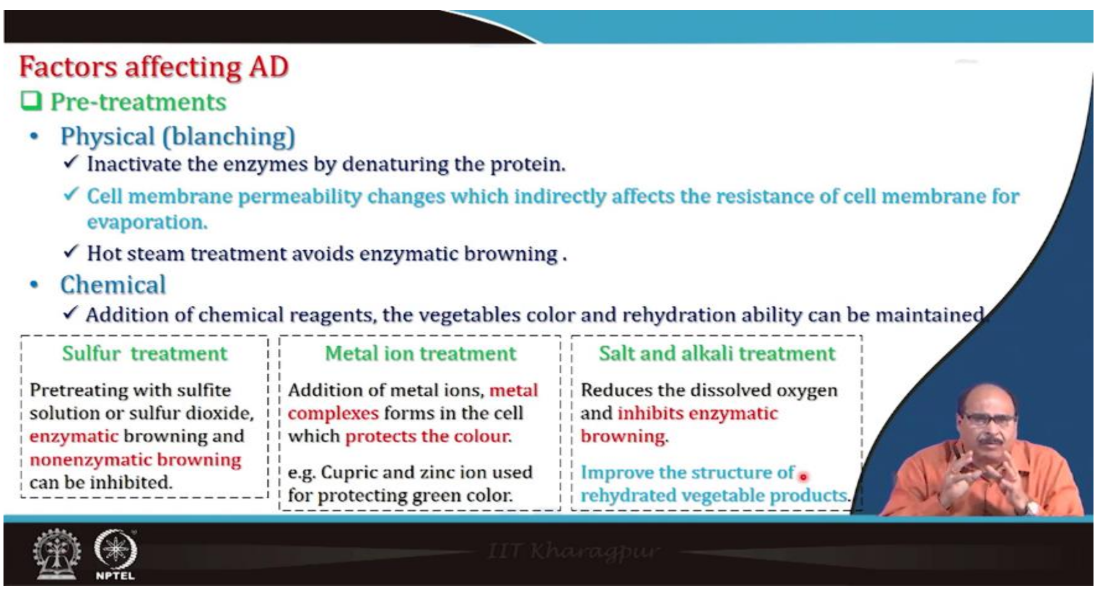
So, air flows through, it goes above the, so heated air goes above and finally humid air outlet, channel is provided. Through this outlet channel, humid air goes out or in some cases, it is recirculated. The recirculating air dryer, that is the, that is air it is coming out, it is again heated and used.

In the mesh belt air dried vegetable dryer, the material is fed through this hopper, conveyed into this dryer with the help of conveyor belt and then it moves. And where it comes in contact with hot air, the moisture leaves out of the surface, and finally that the dryer product is delivered on the other end of the equipment.



Fluidised bed dryer

The hot air flows through the materials quickly, and the fluidized bed is connected with a vibrating motor. With the action of mechanical vibration and hot airflow, the weight of the materials can be balanced in a fluidized state. The advantages of this drying technology are airflow with high temperature and low moisture content achieve high drying rate and energy efficiency, requires low capital investment, is easy to maintain, easy to control, and uniform drying. It is used for drying of the granular vegetables, such as potato dices, apple dices, carrot dices, etc.

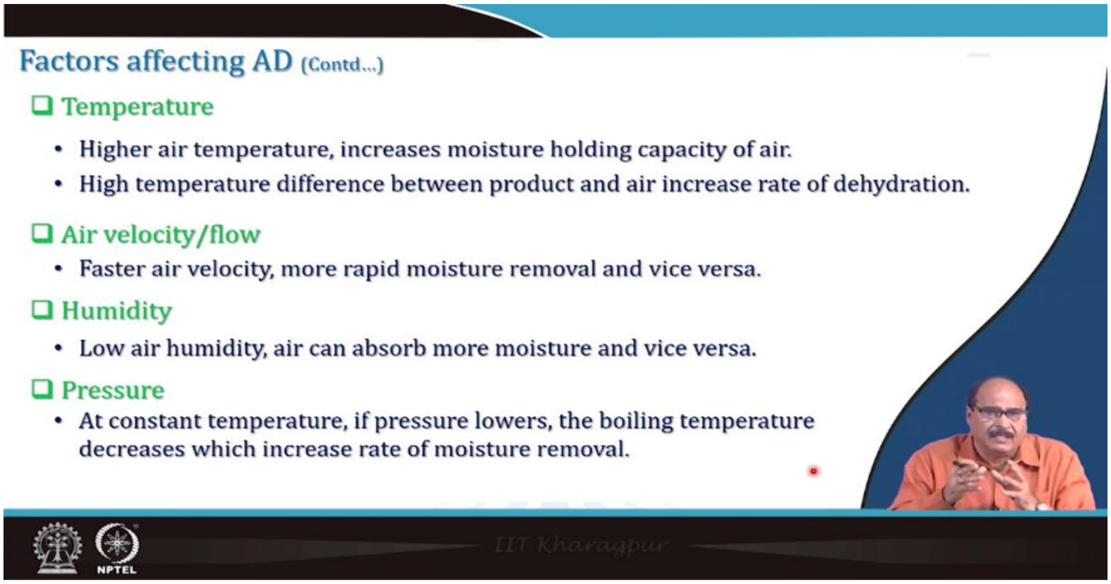


Factors affecting AD

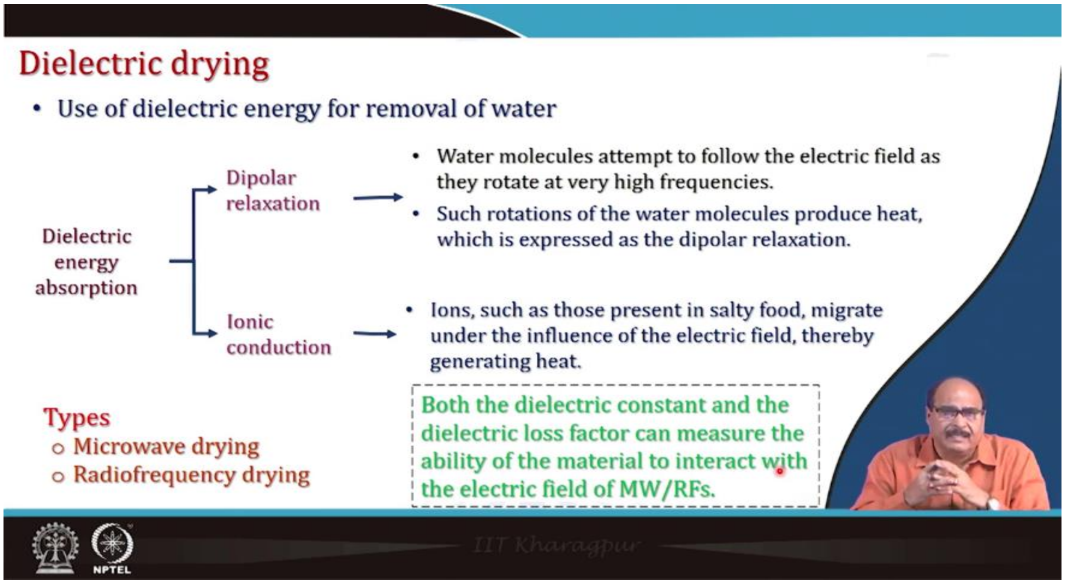
Pre-treatments

Physical (Blanching)

Blanching is used to inactivate the enzymes by denaturing the protein. If the enzymes are not inactivated, it may cause the browning and other problems during the drying process with the activation of the heat. Cell membrane permeability changes which indirectly affects the resistance of cell membrane for evaporation. Hot steam treatment avoids enzymatic browning. Chemical treatments include addition of chemical reagents, the vegetables color and rehydration ability can be maintained. Sulfur treatment involves pretreating with sulfite solution or sulfur dioxide, enzymatic browning and non-enzymatic browning can be inhibited. Metal ion treatment includes the addition of metal ions, metal complexes forms in the cell which protects the color, e.g. Cupric and zinc ion used for protecting green color. Salt and alkali treatment reduces the dissolved oxygen and inhibits enzymatic browning and improves the structure of rehydrated vegetable products.

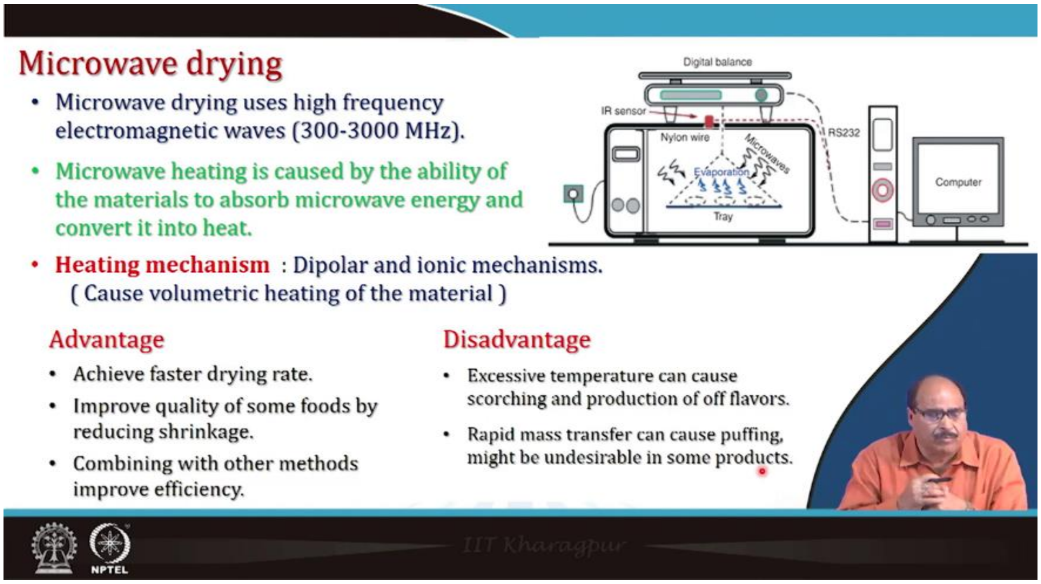


Higher air temperature, increases moisture holding capacity of air. High temperature difference between product and air increase rate of dehydration. Faster air velocity, more rapid moisture removal and vice versa. Low air humidity, air can absorb more moisture and vice versa. At constant temperature, if pressure lowers, the boiling temperature decreases which increase rate of moisture removal.



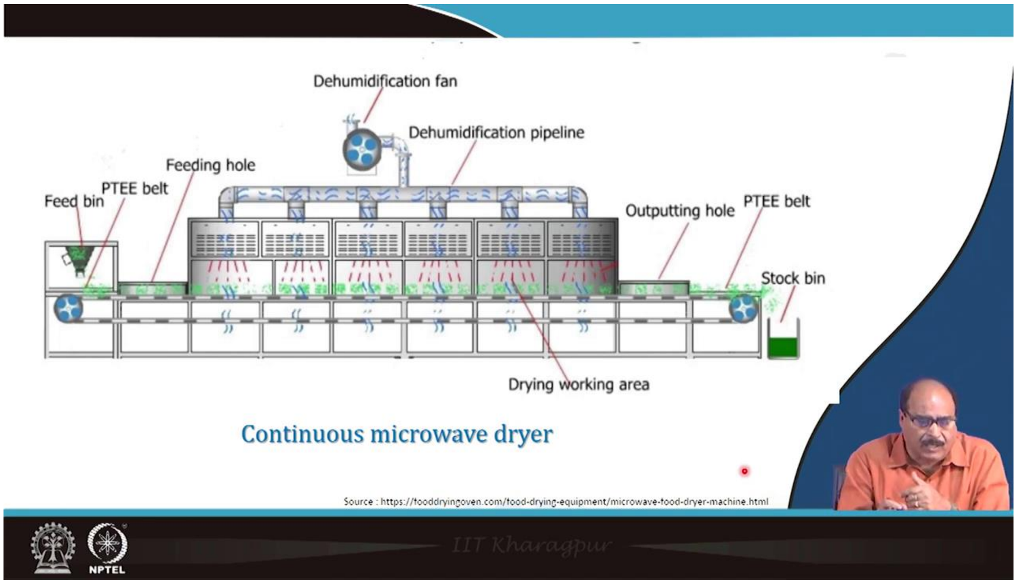
Dielectric drying

This drying uses dielectric energy for removal of water. The dielectric energy absorption takes place by means of dipolar relaxation (where water molecules attempt to follow the electric field as they rotate at very high frequencies, such rotations of the water molecules produce heat, which is expressed as the dipolar relaxation) and ionic conduction (ions, such as those present in salty food, migrate under the influence of the electric field, thereby generating heat).There two types of the dielectric drying are microwave drying and radiofrequency drying. And both these methods are becoming very popular nowadays for the dehydration of fruits and vegetables. Both the dielectric constant and the dielectric loss factor can measure the ability of the material to interact with the electric field of MW/RFs.

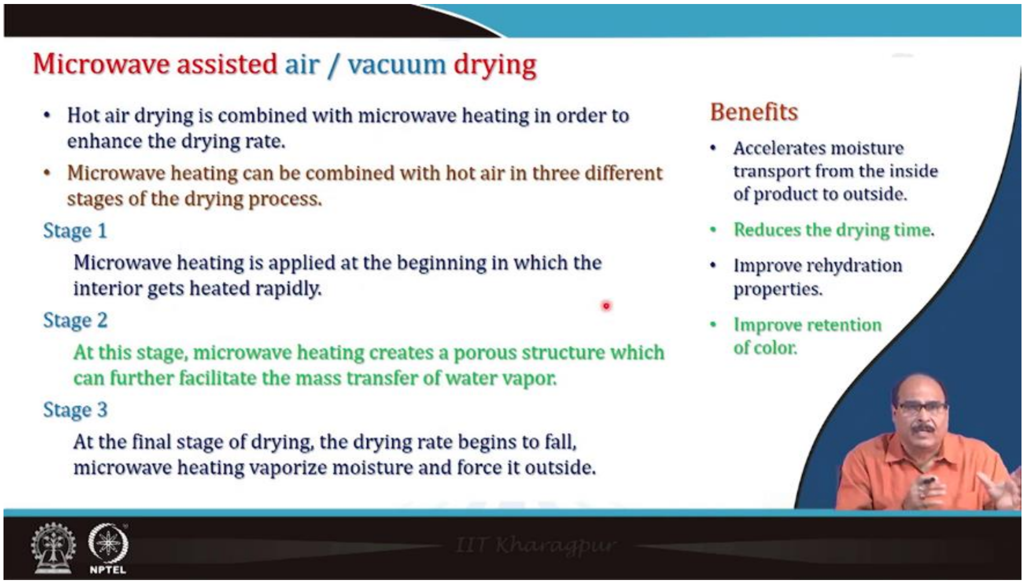


Microwave drying

Microwave drying uses high frequency electromagnetic waves (300-3000 MHz). Microwave heating is caused by the ability of the materials to absorb microwave energy and convert it into heat. This involves the dipolar and ionic mechanisms that cause volumetric heating of the material. The advantages of this drying techniques are faster drying rate, improve quality of some foods by reducing shrinkage, and combining with other methods improve efficiency. Excessive temperature can cause scorching and production of off flavors. Rapid mass transfer can cause puffing, might be undesirable in some products.

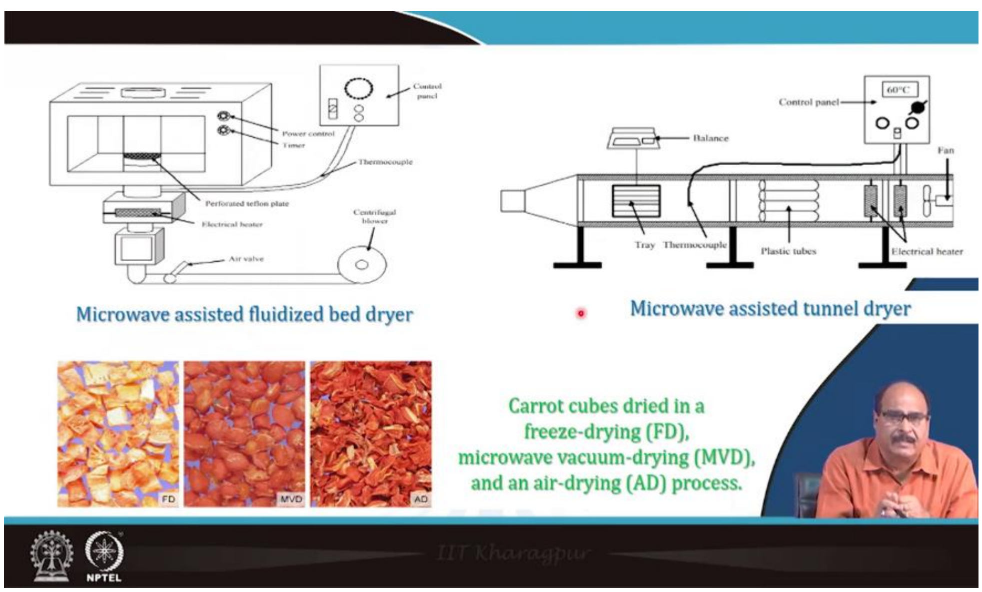


The figure shows the schematic diagram of a continuous microwave dryer. The fruits and vegetables in the form of slices, cubes are fed in the feed bins. With the help of the conveyor belt they are put into the microwave dryer. The products are exposed to the microwave radiation and absorb the microwave, internal heat is generated. Some suitable arrangement in the system is given to take out the moisture, water vapor from the system. And then finally, the dried material is comes, a proper suitable after locking arrangement.

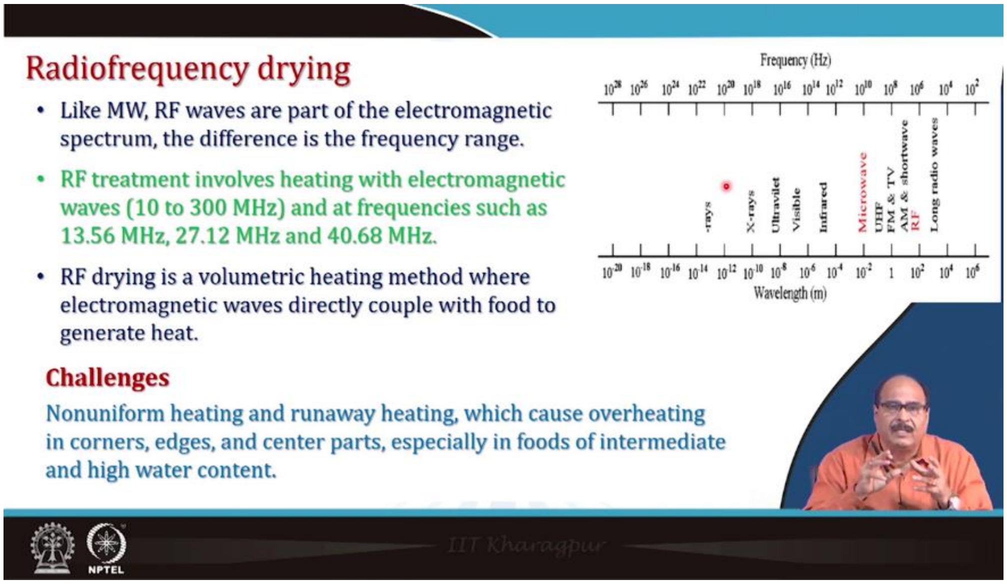


Microwave assisted air/vacuum drying

Hot air drying is combined with microwave heating in order to enhance the drying rate. Microwave heating can be combined with hot air in three different stages of the drying process. In the stage I, microwave heating is applied at the beginning in which the interior gets heated rapidly. In the second stage, microwave heating creates a porous structure which can further facilitate the mass transfer of water vapor. At the final stage of drying, the drying rate begins to fall, microwave heating vaporize moisture and force it outside. It accelerates moisture transport from the inside of product to outside, reduces the drying time, improve rehydration properties, and improve retention of color.

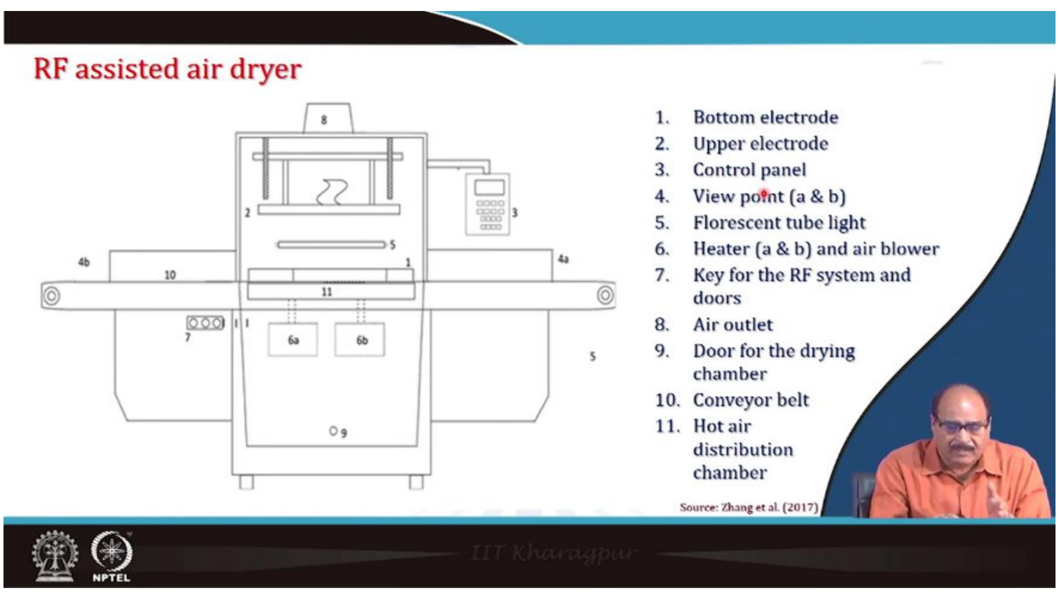


These are the schematic diagram of microwave assisted fluidized bed dryer and microwave assisted tunnel dryer.



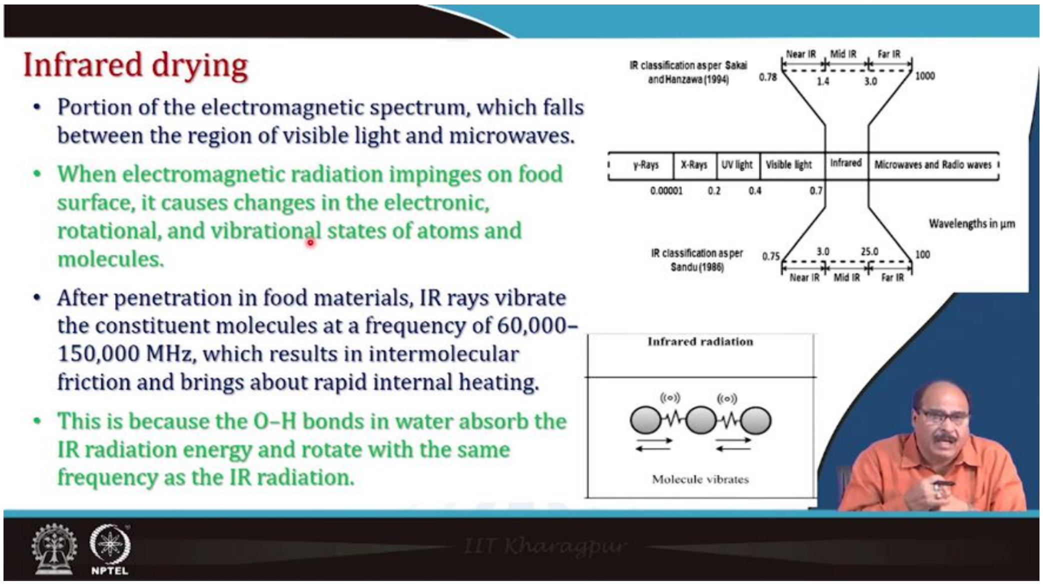
Radiofrequency drying

Like MW, RF waves are part of the electromagnetic spectrum, the difference is the frequency range. RF treatment involves heating with electromagnetic waves (10 to 300 MHz) and at frequencies such as 13.56 MHz, 27.12 MHz and 40.68 MHz. RF drying is a volumetric heating method where electromagnetic waves directly couple with food to generate heat. Non uniform heating and runaway heating, which cause overheating in corners, edges, and center parts, especially in foods of intermediate and high water content.



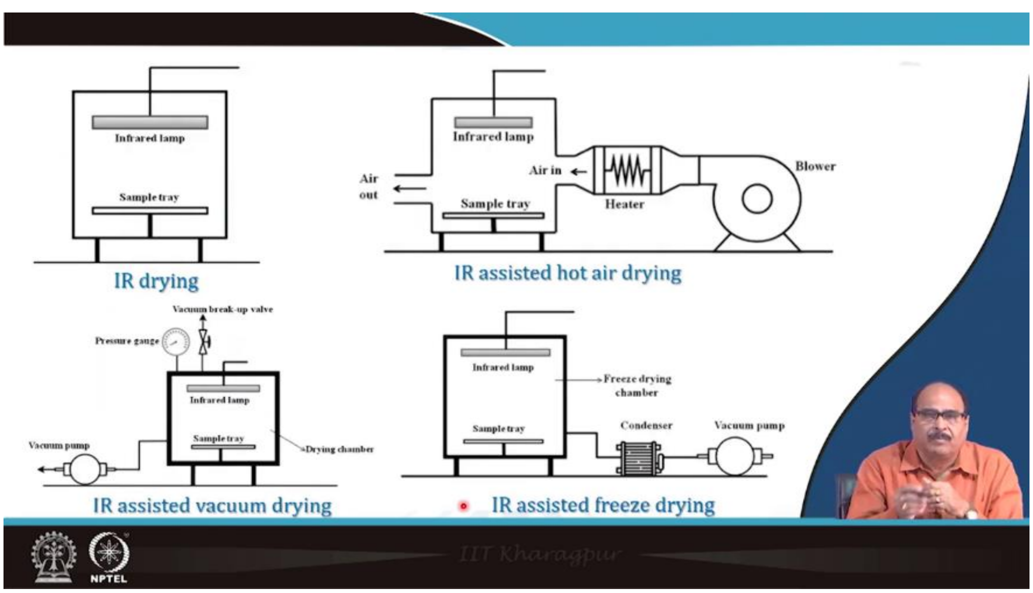
RF assisted air dryer

In a radio frequency assisted air dryer, there are two electrodes one at the bottom and another at the upper side, the material is kept between these electrodes. With the help of conveyor belt, the material is moving and there is a provision for supply of hot air. At the same time when it comes, then radiofrequency waves are provided. And hot air is distributed in the chamber, and this is facilitated by radiofrequency drying. So the drying rate is enhanced.

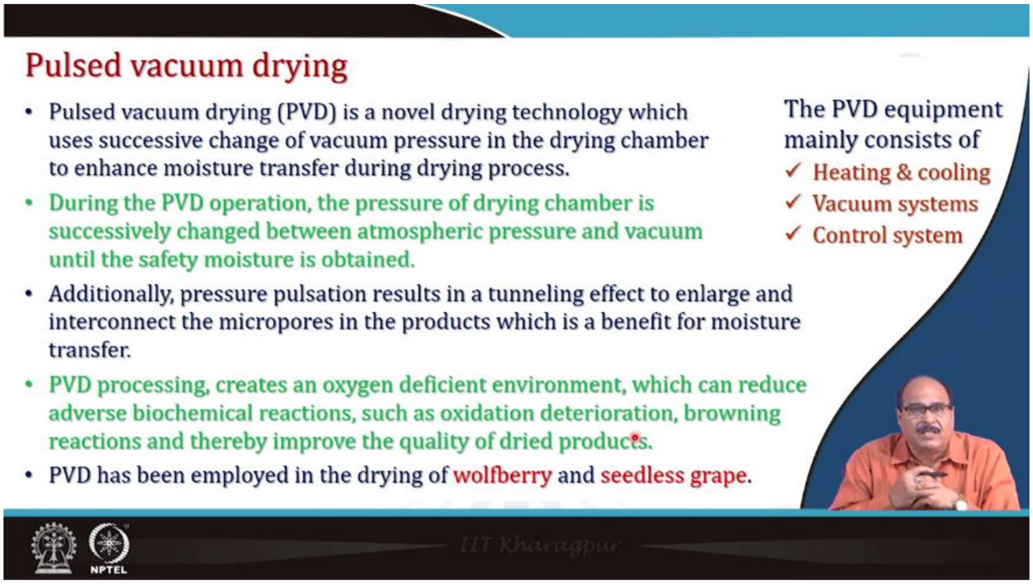


Infrared drying

Portion of the electromagnetic spectrum, which falls between the region of visible light and microwaves. When electromagnetic radiation impinges on food surface, it causes changes in the electronic, rotational, and vibrational states of atoms and molecules. After penetration in food materials, IR rays vibrate the constituent molecules at a frequency of 60,000–150,000 MHz, which results in intermolecular friction and brings about rapid internal heating. This is because the O–H bonds in water absorb the IR radiation energy and rotate with the same frequency as the IR radiation.

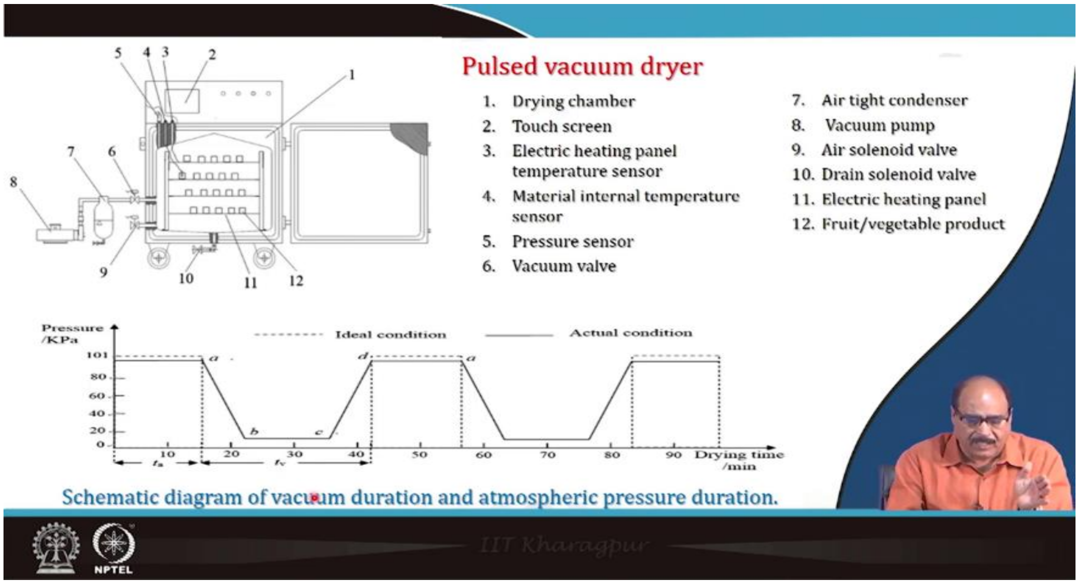


These are the different arrangements of IR drying such as simple IR drying, IR assisted hot air drying, IR assisted vacuum drying, and IR assisted freeze drying. In infrared assisted hot air drying, infrared lamp chamber is there where some additional supply of hot air is provided. Infrared assisted vacuum drying that is along with this supply, there is also chamber is provided with a vacuum pump to reduce heat that, which can facilitate the vaporization at a lower temperature. And then infrared assisted freeze drying, the freeze drying principles are employed. The lower temperature condensers that are provided to reduce the temperature to -23 or -50 ˚C.



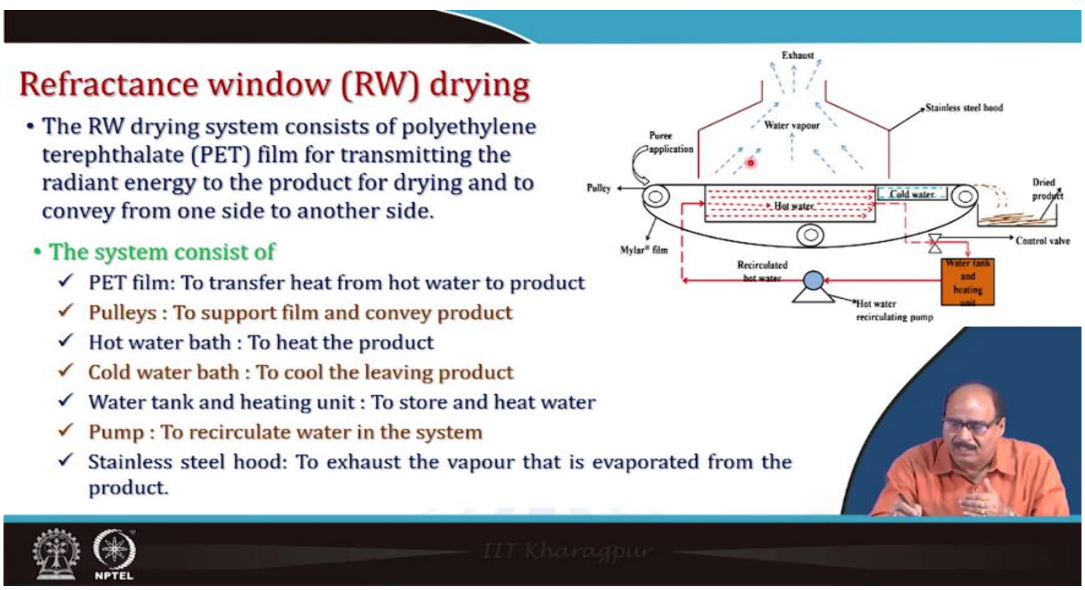
Pulsed vacuum drying

Pulsed vacuum drying (PVD) is a novel drying technology which uses successive change of vacuum pressure in the drying chamber to enhance moisture transfer during drying process. During the PVD operation, the pressure of drying chamber is successively changed between atmospheric pressure and vacuum until the safety moisture is obtained. Additionally, pressure pulsation results in a tunneling effect to enlarge and interconnect the micropores in the products which is a benefit for moisture transfer. PVD processing, creates an oxygen deficient environment, which can reduce adverse biochemical reactions, such as oxidation deterioration, browning reactions and thereby improve the quality of dried products. PVD has been employed in the drying of wolfberry and seedless grape. The PVD equipment mainly consists of a heating and cooling system, vacuum generation system, vacuum creation system, and the control system.



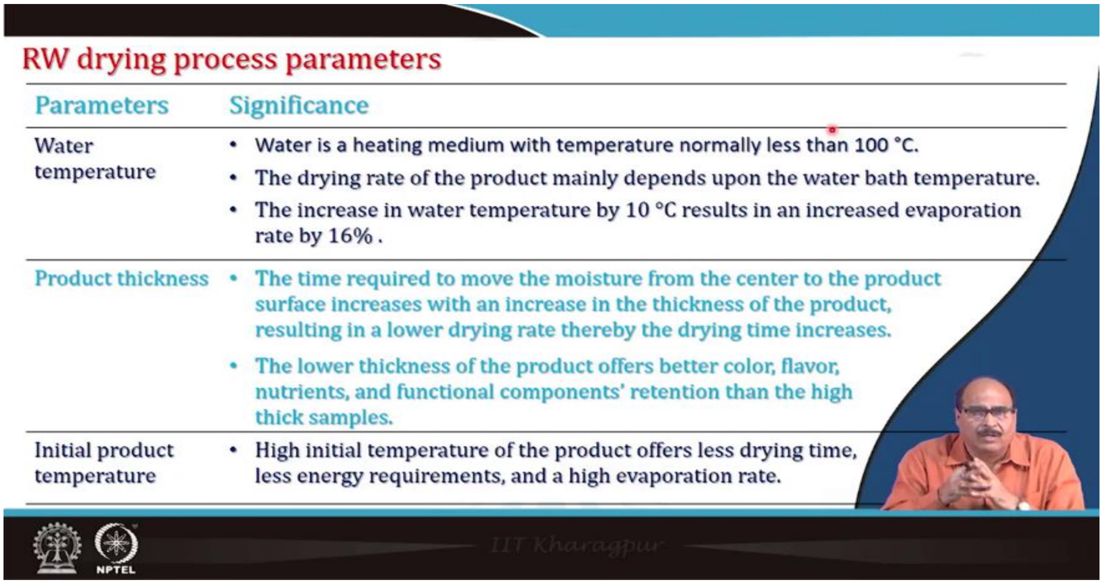
Pulsed vacuum dryer

It consists of drying chamber, touch screen, electric heating panel temperature sensor, material internal temperature sensor, pressure sensor, vacuum valve, air tight condenser, vacuum pump, air solenoid valve, drain solenoid valve, electric heating panel. This is a schematic diagram of vacuum duration and atmospheric pressure. So, this successively, that material inside is brought to the low pressure, that is vacuum created and then it is released, then vacuum created, then it is released in order to provide a better frying efficiency.



Refractance window (RW) drying

The RW drying system consists of polyethylene terephthalate (PET) film for transmitting the radiant energy to the product for drying and to convey from one side to another side. The system consists of PET film (To transfer heat from hot water to product), pulleys (To support film and convey product), hot water bath (To heat the product), cold water bath (To cool the leaving product), water tank and heating unit (To store and heat water), pump (To recirculate water in the system), stainless steel hood (To exhaust the vapour that is evaporated from the product).



RW drying process parameters

Water temperature

Water is a heating medium with temperature normally less than 100 °C. The drying rate of the product mainly depends upon the water bath temperature. The increase in water temperature by 10 °C results in an increased evaporation rate by 16%.

Product thickness

The time required to move the moisture from the center to the product surface increases with an increase in the thickness of the product, resulting in a lower drying rate thereby the drying time increases. The lower thickness of the product offers better color, flavor, nutrients, and functional components’ retention than the high thick samples.

Initial product temperature

High initial temperature of the product offers less drying time, less energy requirements, and a high evaporation rate.

Residence time

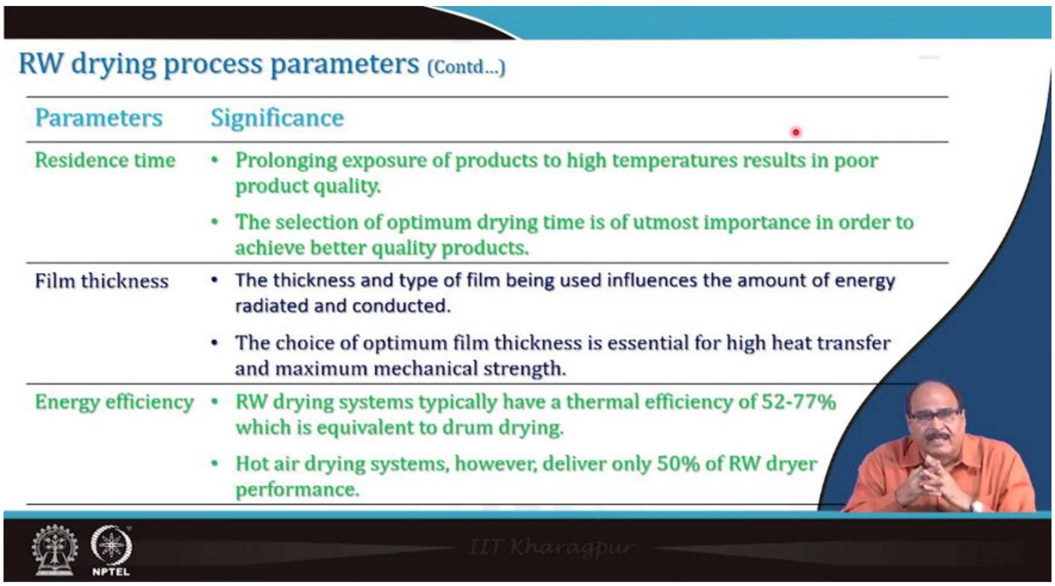
Prolonging exposure of products to high temperatures results in poor product quality. The selection of optimum drying time is of utmost importance in order to achieve better quality products.

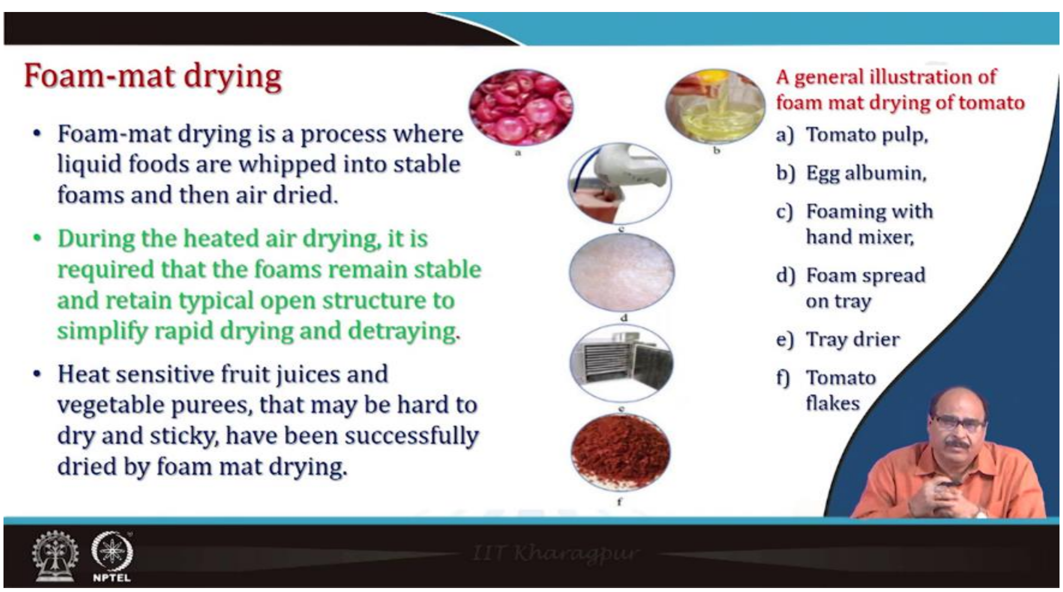
Film thickness

The thickness and type of film being used influences the amount of energy radiated and conducted. The choice of optimum film thickness is essential for high heat transfer and maximum mechanical strength.

Energy efficiency

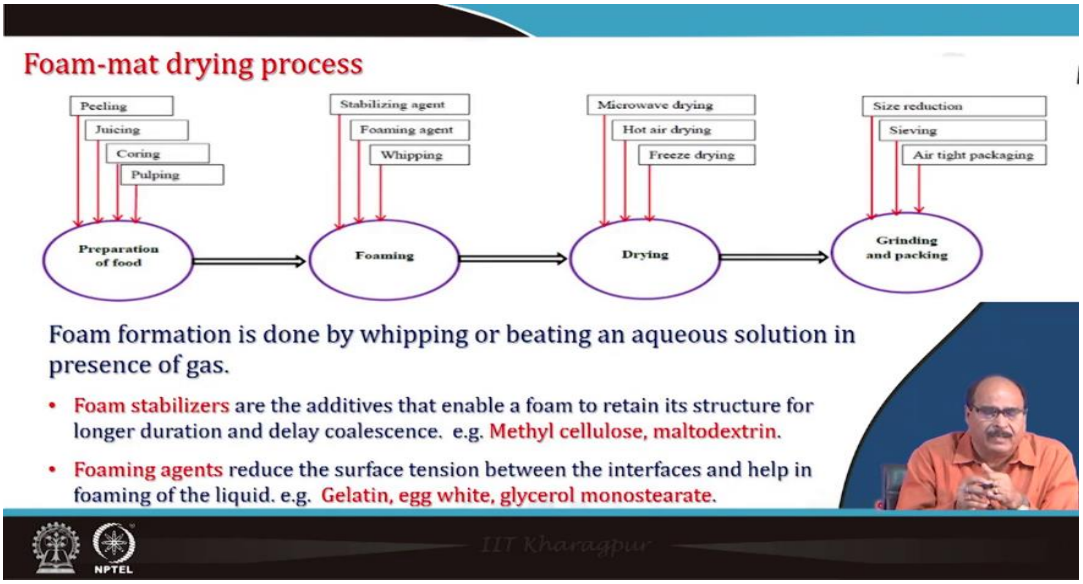
RW drying systems typically have a thermal efficiency of 52-77% which is equivalent to drum drying. Hot air drying systems, however, deliver only 50% of RW dryer performance.





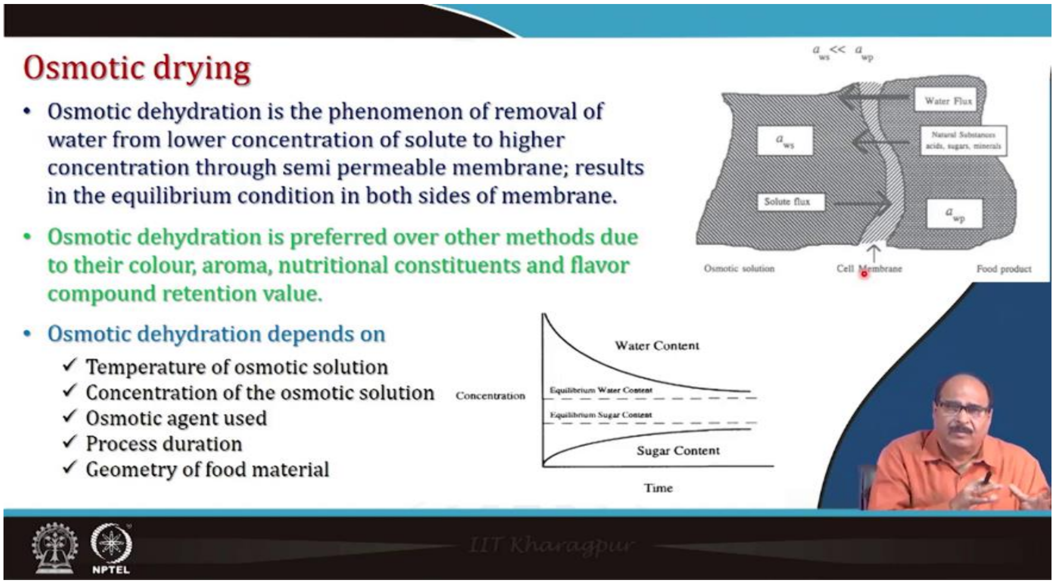
Foam-mat drying

Foam-mat drying is a process where liquid foods are whipped into stable foams and then air dried. During the heated air drying, it is required that the foams remain stable and retain typical open structure to simplify rapid drying and detraying. Heat sensitive fruit juices and vegetable purees, that may be hard to dry and sticky, have been successfully dried by foam mat drying.



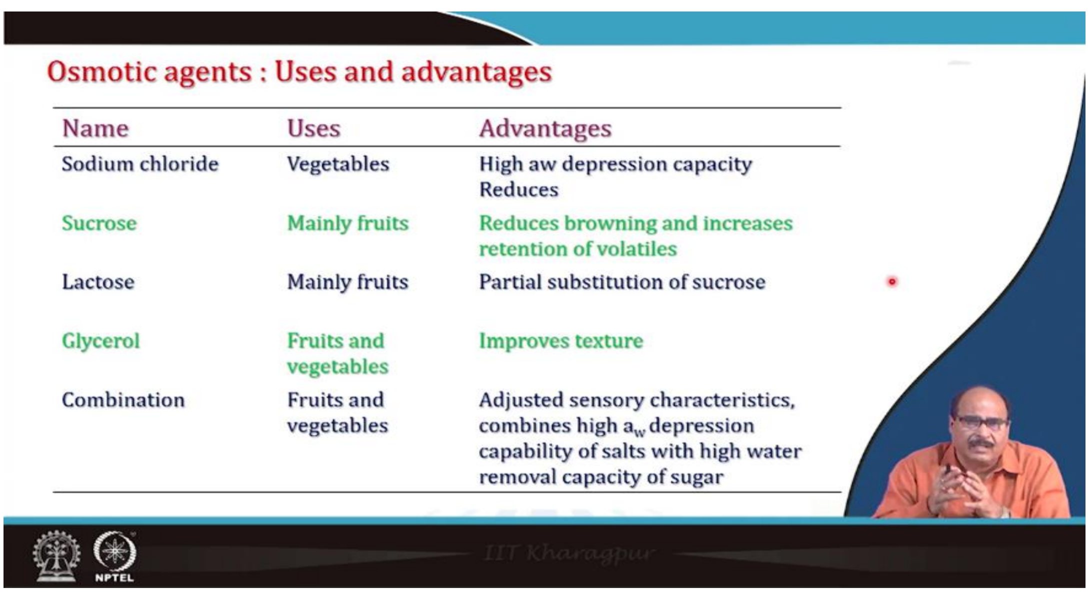
Foam-mat drying process

The first step is the preparation of food, which includes peeling, juicing, coring, and pulping. The second step is foam formation, where stabilizing and foaming agents are added and whipping action takes place. Foam formation is done by whipping or beating an aqueous solution in presence of gas. Foam stabilizers are the additives that enable a foam to retain its structure for longer duration and delay coalescence, e.g. Methyl cellulose, maltodextrin. Foaming agents reduce the surface tension between the interfaces and help in foaming of the liquid, e.g. Gelatin, egg white, glycerol monostearate. The third step is drying by microwave, hot air, or freeze drying. So, because of the higher surface area, the drying rate is enhanced. The dried products in the form of flakes are subjected to size reduction, sieving, and finally packed.



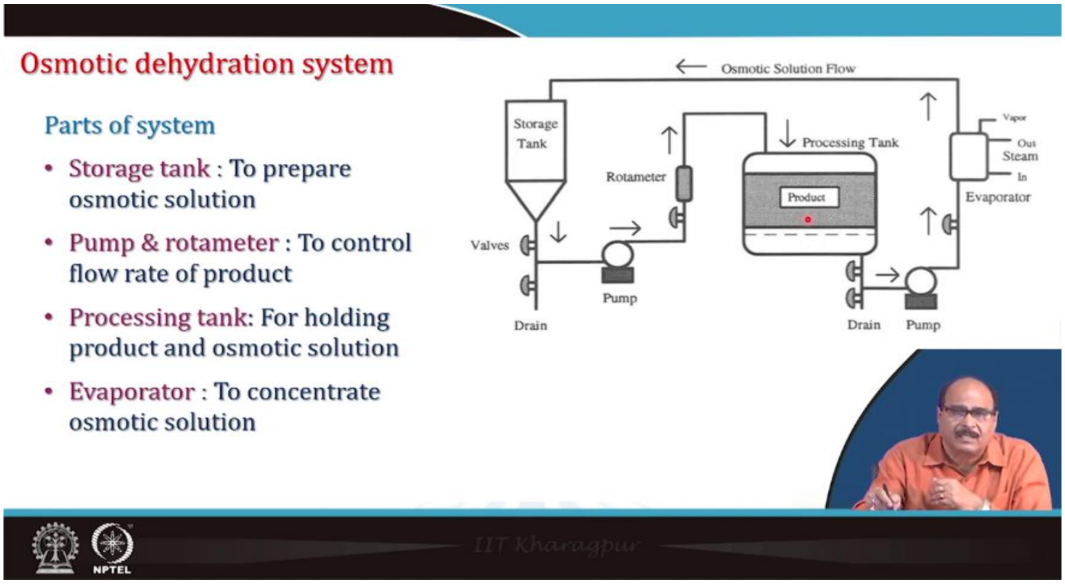
Osmotic drying

Osmotic dehydration is the phenomenon of removal of water from lower concentration of solute to higher concentration through semi permeable membrane; results in the equilibrium condition in both sides of membrane. Osmotic dehydration is preferred over other methods due to their colour, aroma, nutritional constituents and flavor compound retention value. Osmotic dehydration depends on the temperature of the osmotic solution, concentration of the osmotic solution, osmotic agents, process duration, and geometry of the food material, whether it in form of a thin seed, in the form of a cube, thick tube, fingers etc.



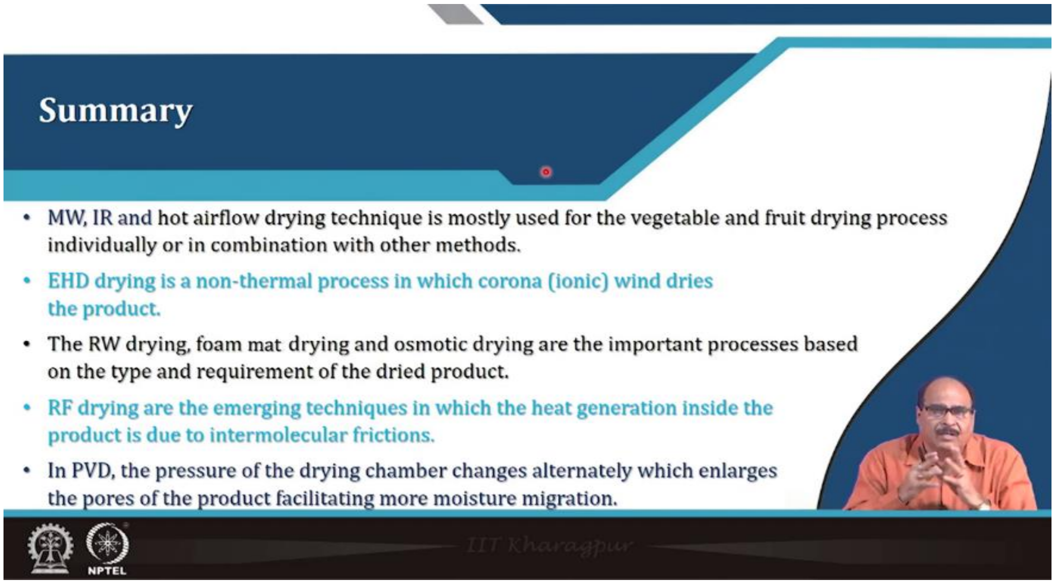
Osmotic agents: Uses and advantages

Sodium chloride is used for in vegetables to reduce the high a_w depression capacity. Sucrose and lactose are mainly used for the fruits, particularly it reduces browning and increases retention of volatiles, and partial substitution of sucrose. Glycerol can be used for both fruits and vegetables, it improves texture. Combination of the osmotic agents can be used for fruits and vegetables.

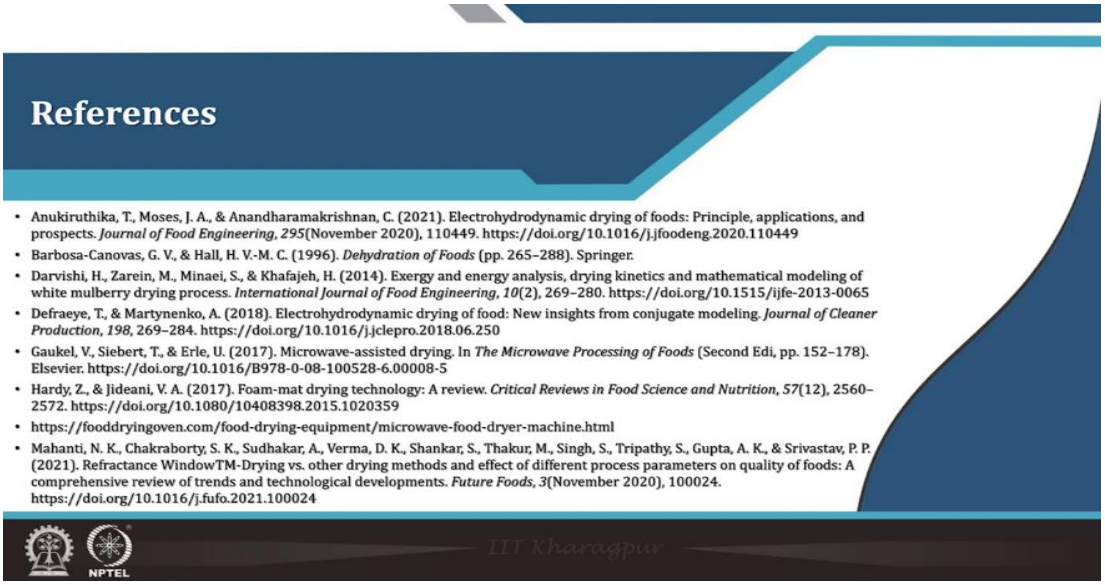


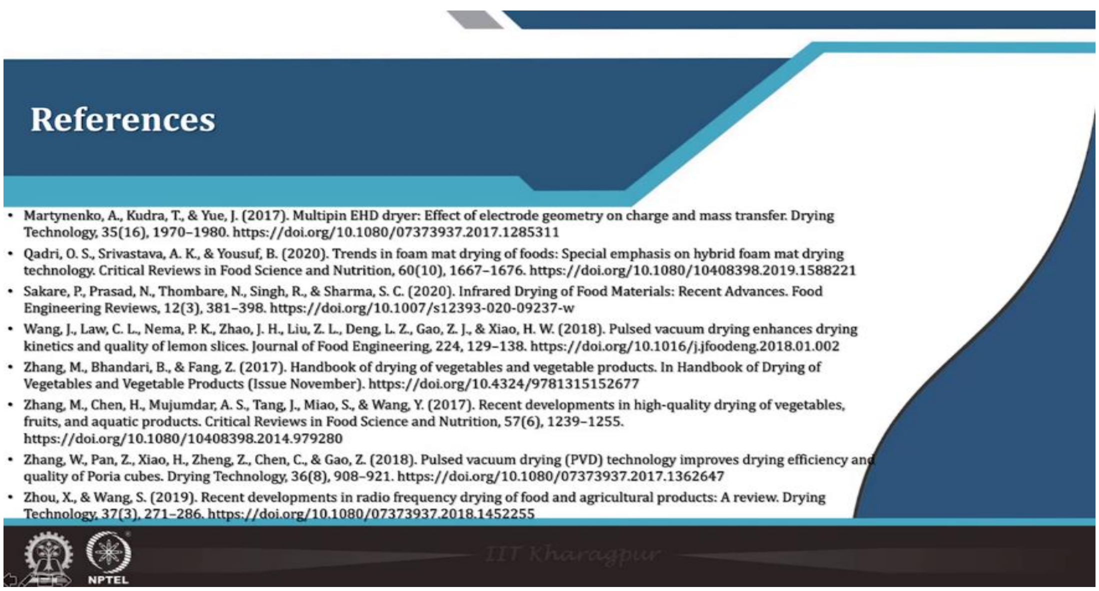
Osmotic dehydration system

There is a storage tank which is used for the preparation of the osmotic solution and then with the help of suitable pumps and rotometer, osmotic solution is supplied into the product processing tank. And in this processing tank, the pump rotameter is used to control the flow rate and processing tank for holding the product and osmotic solution. And finally, there is an evaporator chamber to concentrate the osmotic solution.



In summary, MW, IR and hot airflow drying technique is mostly used for the vegetable and fruit drying process individually or in combination with other methods. EHD drying is a non-thermal process in which corona (ionic) wind dries the product. The RW drying, foam amt drying and osmotic drying are the important processes based on the type and requirement of the dried product. RF drying are the emerging techniques in which the heat generation inside the product is due to intermolecular frictions. In PVD, the pressure of the drying chamber changes alternately which enlarges the pores of the product facilitating more moisture migration.





These are the references for further study. Thank you.